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WIND RESOURCE ASSESSMENT: TRACY, MONTANA

Prepared for

MONTANA DEPARTMENT of NATURAL RESOURCES and CONSERVATION

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Wind resource assessment: Tracy, Montana
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WIND RESOURCE ASSESSMENT: TRACY, MONTANA

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June, 1977

Prepared for

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32 South Ewing, Helena, Montana 59620
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SUMMARY

Drapes Engineering has carried out a Contract with the Department of Natural Resources and Conservation for the purpose of evaluating the wind power generation potential of a site near Tracy, outside Great Falls, Montana.

An energy balance on wind systems, which compares the energy expended to produce the system with the energy output of the system during its useful life, shows that it is possible to realize a net energy loss with wind systems in areas having low power generation potential. To avoid this situation, it is important to accurately assess the wind power characteristics at a potential site prior to system installation.

The project site is located in hilly terrain, approximately 12 miles east by southeast of the Great Falls Airport, where long-term weather data have been recorded. Although weather records are reliable indicators of some wind characteristics, such as seasonal and diurnal variations, these data are not recorded for the purpose of power generation estimations. Measurements taken are instantaneous wind speeds, recorded hourly, which may not reflect typical conditions for each hour.

In consideration of these facts, Drapes Engineering proposed to monitor the test site and record the information necessary to establish its power generation potential. This was accomplished by making continuous measurements for a one-month period during April, 1977. The results of these measurements were then compared to the Weather Bureau wind speed records for the same time period at the Great Falls Airport. The results of this one-month comparison showed that the site selected has at least as good a wind power generation potential as that indicated by the Weather Bureau records for the same time period. This is considered substantial evidence that the selected site has a long-term power generation potential which is well above that required for a net energy gain with a wind system.

The quantitative details of the measured data and data analysis are presented in the following report.

DATA MEASUREMENT

The weather monitoring instruments consisted of a three-cup anemometer, two temperature sensors, wind direction vane, and solar pyranometer. One temperature sensor, the anemometer and direction vane were mounted atop a 38' guyed tower. The solar pyranometer was mounted on the roof of the equipment shed. The second temperature sensor monitored the inside temperature of the shed. Refer to Figure 1 for project and equipment photographs.

The equipment shed was a 4' x 4' x 4' weather-tight building, enclosing the electronic digital interface equipment. This building was heated with a 300 watt light bulb controlled by a thermostat. Two inches of rigid insulation were used to minimize the effect of outside weather conditions.

The digital electronic equipment converted signals from all the instruments to the following output: temperatures in degrees Fahrenheit, instantaneous wind speed in miles per hour, cumulative run of wind in miles, wind direction in 16 quadrants, instantaneous solar insolation in watts per square meter and cumulative solar insolation in watt-hours per square meter. This digital interface system operated on 24 volts dc supplied by two 12-volt automotive batteries connected in series. The batteries were recharged from a 110 volt ac source. All converted digital data were output to a punched paper tape. In this manner, the data monitoring system was able to operate uninterrupted by power failures for extended periods of time. The site was never unattended for longer than 3 days during the test period.

A sample of the raw data output from the punched paper tape is presented in Table 1. The time is presented by hour, minutes, seconds and the day is the day of the year. In the example presented, the time starts at 2:30 p.m. on April 6th. A sample of the data recorded at the Great Falls Airport for April 6th is presented in Table 2.

The data monitoring system was installed on the test site and began operation at 12:30 p.m. March 27th. The system was disassembled at 3 p.m. on May 2nd. Continuous data was recorded for the test period of April 1 thru April 30.

Three problem areas were identified during the course of the data acquisition. The direction indicator stopped functioning, temperature records were inconclusive for ambient temperatures over 80 degrees F, and wind speed records with northerly winds were too low. The first two problems occurred in prototype rental equipment and have since been rectified. The lack of this information does not affect the results of the project. The low wind speed records from a northerly direction resulted from a design problem in the wind instrument, which has since been changed. Since northerly winds occurred only a small percent of the time during April, this problem was not considered to be a substantial error so far as the final results are concerned.

DATA ANALYSIS

The most important wind characteristic from the standpoint of wind power generation is the energy density. Energy density is a measure of the amount of kinetic energy per unit area perpendicular to the direction of horizontal wind flow that passes a reference point in a given period of time. Energy density calculations are outlined in Appendix A.

The energy density for the month of April at the Tracy Wind Power Site was based on hourly records of cumulative wind flow and on ambient temperature conditons at the 38' tower height. The hourly wind speed readings, taken at a tower height of 22' at the Great Falls Airport, were assumed to represent cumulative wind flow for the energy density calculations. The Weather Bureau wind speed data was height corrected from 22' to 38' by the procedure outlined in Appendix B. Ambient air temperatures at the Airport were also used.

The energy density for the month of April at the Tracy Wind Power Site was 114.0 kwh/square meter. The energy density computed for the Great Falls Airport for April was 113.8 kwh/square meter. Based on the energy density parameter, the wind power generation potential of both sites is nearly identical.

One other meaningful comparison of power generation potential at the two sites is to evaluate the performance of a wind system at both locations. Care must be used with such a comparison, since windplants are usually designed for certain wind conditions. In this case, the comparison should be valid since both sites have very similar power generation potential. The wind electric system chosen for comparison consisted of a Dunlite 2000 windplant, which shared the electric load with the existing power company network thru a synchronous inverter. With this system configuration, the windplant is assumed to be fully loaded under all operating conditions. This windplant has a cut-in speed of 8 mph and a full rated output of 2 kw at 25 mph. The tabulated characteristic performance of this windplant is listed in Appendix D and the method of calculating the monthly energy output is outlined in Appendix C. The estimated energy production at the Tracy Site was 414 kwh/mo. and that at the Great Falls Airport was 403 kwh/mo. Although this difference is insignificant, the conclusion can be drawn that the Tracy Wind Power Site has a power generation potential equal to that of the Great Falls Airport.

It should be emphasized that several important assumptions have been made with the Weather Bureau data taken at the Great Falls Airport. One assumption is that the instantaneous hourly wind speed readings are representative of the average wind conditions for that hour. The second assumption is that the recorded data can be height corrected in the manner outlined in Appendix B. This should be a valid assumption for the prevailing westerly and southwesterly winds at the Airport, since the approach from that direction is over flat and unobstructed terrain.

Without the height correction, the energy density at the Airport was 81.8 kwh/square meter, a decrease of 28% from the height corrected data. Similarly, the windplant energy output was 318 kwh/mo. for the uncorrected data, a reduction of 21% from the height corrected data.

A tabular summary of wind conditions at both sites is presented in Tables 3 and 4. The monthly mean speeds are listed as 12.6 mph and 11.8 mph for the Airport and the Tracy Sites, respectively. Although the Tracy Site shows a 6% lower mean wind speed than the Airport location, its power generation potential is equal to, or greater than, that at the Airport. This emphasizes the importance of using the frequency distribution of wind speeds (from which energy density and windplant power output are computed) rather than the mean speed as a parameter for comparison of power generation potential. The frequency distributions for both sites are listed in Appendix E.

A daily summary of mean speed, energy density and windplant energy output are listed in Tables 5 and 6 for the Tracy Wind Power Site and the Great Falls Airport, respectively. The data files used for the computer analysis of wind power characteristics are listed in Appendix F. The data file for the Tracy Site lists day of the year, hour of the day, ambient temperature in degrees Fahrenheit, run of wind in miles and cumulative solar radiation in wh/square meter. The data file for the Great Falls Airport lists day of the year, hour of the day, ambient temperature in degrees Fahrenheit and wind speed in knots.

Measured values of daily total solar radiation on a horizontal surface at the Wind Power Site are tabulated in Table 7. Weather Bureau data for the same measurement was not available. The monthly average value of total insolation, 2032 Btu/ft^2 - day, was 27% above the long term average for the month of April (1600 Btu/ft^2 - day).

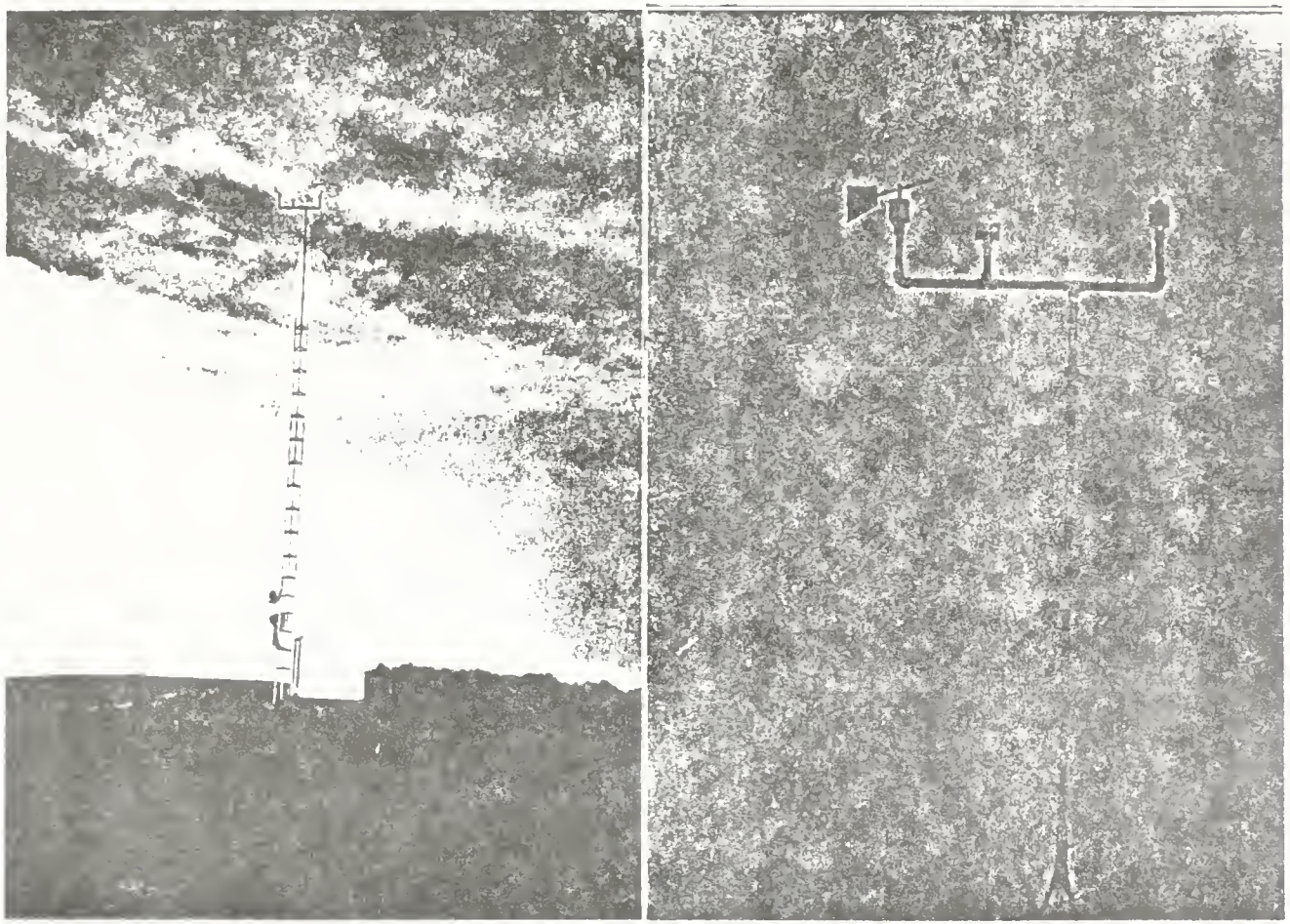

FIGURE 1. SITE PHOTOGRAPHS

04/08/77

W E A T H E R R E P O R T

TIME	DAY	TEMP1	TEMP2	WIND	CUM.FLOW	DIR	SOLAR	CUM.SOLAR
14:30:01	96	+065.5	+069.2	17	674.12	08	820	547
14:45:01	96	+064.9	+069.5	16	678.21	08	790	748
15:00:01	96	+065.8	+069.8	16	682.48	08	752	941
15:15:01	96	+067.0	+070.0	12	686.35	08	715	1124
15:30:01	96	+066.3	+070.4	10	689.84	08	673	1298
15:45:01	96	+067.2	+070.8	15	692.95	08	630	1461
16:00:01	96	+068.2	+071.1	16	696.23	08	581	1612
16:15:01	96	+067.8	+071.3	13	699.58	08	530	1750
16:30:01	96	+067.3	+071.5	16	703.04	08	476	1876
16:45:01	96	+067.6	+071.6	10	706.26	08	421	1988
17:00:01	96	+067.4	+071.6	17	709.46	08	364	2086
17:15:01	96	+067.6	+071.8	13	712.67	08	310	2170
17:30:01	96	+067.7	+071.7	11	715.79	08	253	2240
17:45:01	96	+067.6	+071.5	12	718.92	08	198	2297
18:00:01	96	+067.3	+077.0	11	721.85	08	145	2339
18:15:01	96	+065.2	+074.0	11	724.47	08	97	2368
18:30:01	96	+063.0	+073.0	11	727.14	08	52	2386
18:45:01	96	+060.0	+069.4	8	728.99	08	11	2392
19:00:01	96	+056.8	+070.4	10	731.21	08		2393
19:15:01	96	+054.6	+069.2	11	733.80	08		2393
19:30:01	96	+053.8	+067.7	12	736.96	08		2393
19:45:01	96	+051.4	+066.6	12	739.99	08		2393

TABLE 1

TABLE 2

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

STATION: T FALLS MONTANA INT

SURFACE WEATHER OBSERVATIONS

DATE: APR 6 1977

TO CONVERT LST TO G ADD 7 hrs SUBTRA

TIME (LST) (21)	SKY AND CEILING (Hundreds of Feet) (31)	VISIBILITY (Miles) SURFACE (14)	VISIBILITY (Miles) TOWER (14a)	WEATHER AND OBSTRUCTIONS TO VISION (51)	SEA LEVEL PRESS. (Mbs.) (61)	TEMP. (°F) (71)	DEW PT. (°F) (81)	WIND DIRECTION (10s-36) (19)	WIND SPEED (Kts.) (101)	WIND GUSTS (111)	ALTIMETER SETTING (Ins.) (112)	REMARKS AND SUPPLEMENTAL CODED (113)
0055	250 SCT	15			203	42	21	22	09		012	
0155	CLR	15			200	42	20	21	06		012	105
0255	CLR	15			200	42	21	22	03		012	
0355	CLR	15			202	41	20	22	02		012	
0455	CLR	15			205	41	21	22	02		013	303 40 RADAT 30
	72775 02212 74020 20505	0 0900	0 5630		3	68	92	7	46	5 40	0	
0555	CLR	50			213	46	21	22	11		015	
0655	CLR	75			222	44	22	22	02		016	
0755	CLR	75			231	48	22	23	02		018	317
0855	CLR	75			241	51	25	22	14		020	
0955	CLR	75			231	58	26	24	13		021	
1055	CLR	75			241	60	22	23	12		022	110 39
	72775 02312 89020 2411	6	009	00 5611	0	68	95	4	46	1 39	0	
1155	CLR	75			234	63	21	25	08		021	
1255	CLR	75			226	65	22	23	09		020	
1355	CLR	75			224	66	22	23	08		019	608
1455	CLR	75			220	66	20	20	06		018	CI NW-NE
1555	CLR	75			214	67	18	23	05		017	CI NW-NE
1655	CLR	75			211	67	18	00	08		016	CI NW-NE / 710 10
												67 RADAT 2010
	72775 10080 89020	2 1119		009	02	58	710		68	935	5	467390
1755	CLR	75			215	62	22	17	05		016	CI NW-NE
1855	900 SCT	75			209	64	21	16	09		015	
1955	200 SCT	15			214	55	24	19	09		015	602 1002
2055	200 SCT	15			213	53	22	20	07		015	
2155	CLR	15			215	47	21	22	08		016	
2255	CLR	15			220	44	20	23	09		017	307 67
	72775 02309 74020	2 2007		00900		57	307		68	939	20000	467390
2355	CLR	15			221	42	20	21	00		018	

TABLE 3

MONTHLY SUMMARY OF WIND CHARACTERISTICS FOR
THE TRACY WIND POWER SITE
MONTH OF APRIL 1977

MONTHLY AVERAGE WIND SPEED = 11.84 MPH

MONTHLY ENERGY DENSITY = 114.02 KWH/ SQUARE METER

MONTHLY ENERGY OUTPUT OF DUNLITE WINDPLANT = 413.92 KWH/MONTH

TABLE 4

MONTHLY SUMMARY OF WIND CHARACTERISTICS FOR
THE GREAT FALLS INTERNATIONAL AIRPORT WEATHER STATION
MONTH OF APRIL 1977

MONTHLY AVERAGE WIND SPEED = 12.63 MPH

MONTHLY ENERGY DENSITY = 113.76 KWH/ SQUARE METER

MONTHLY ENERGY OUTPUT OF DUNLITE WINDPLANT = 402.78 KWH/MONTH

TABLE 5

DAILY LISTING OF WIND CHARACTERISTICS FOR
THE TRACY WIND POWER SITE
MONTH OF APRIL 1977

DAY OF THE MONTH	DAILY MEAN WIND SPEED (MPH)	DAILY MEAN ENERGY DENSITY (WATT-HR/M2)	DAILY ENERGY PRODUCTION OF WINDPLANT (KWH)
1	6.5	1032	3.8
2	8.1	1373	5.3
3	12.8	5627	18.8
4	11.5	2207	10.7
5	13.8	4541	18.3
6	13.0	2738	13.7
7	14.1	3481	17.7
8	20.4	11728	33.7
9	13.3	4492	17.9
10	13.9	4343	18.1
11	13.6	4362	18.1
12	12.9	3514	15.6
13	18.0	9516	27.9
14	11.5	2459	10.9
15	18.5	9134	30.0
16	15.1	6172	21.2
17	9.5	1757	8.1
18	8.4	1175	4.3
19	9.9	1922	9.1
20	7.0	1252	5.1
21	7.0	954	4.4
22	9.7	1699	8.2
23	9.8	2948	8.3
24	8.9	1565	6.6
25	8.7	1756	6.6
26	13.2	4203	17.8
27	12.1	3446	14.1
28	5.7	354	1.0
29	12.7	6789	15.7
30	16.2	7478	22.8

TABLE 6

DAILY LISTING OF WIND CHARACTERISTICS FOR
THE GREAT FALLS INTERNATIONAL AIRPORT WEATHER STATION
MONTH OF APRIL 1977

DAY OF THE MONTH	DAILY MEAN WIND SPEED (MPH)	DAILY MEAN ENERGY DENSITY (WATT-HR/M2)	DAILY ENERGY PRODUCTION OF WINDPLANT (KWH)
1	12.3	3126	11.7
2	10.8	2130	8.1
3	13.7	5714	19.9
4	10.5	1497	5.4
5	14.7	4342	17.9
6	12.3	2743	12.5
7	12.5	2675	11.8
8	17.3	7287	26.3
9	17.0	8194	24.1
10	15.1	5456	19.3
11	12.3	2883	12.3
12	13.3	3571	14.6
13	19.4	9064	32.5
14	12.2	2750	10.4
15	16.3	6603	22.3
16	18.6	11811	27.6
17	10.6	2010	7.8
18	11.2	2591	9.6
19	11.1	2281	8.9
20	8.6	939	2.9
21	7.3	790	2.3
22	10.8	2205	9.0
23	9.6	1362	5.5
24	8.3	928	3.6
25	8.1	714	2.8
26	15.1	5684	21.7
27	13.6	3909	15.4
28	7.4	621	1.4
29	12.9	4104	13.9
30	16.1	5777	21.9

TABLE 7

DAILY LISTING OF TOTAL SOLAR INSOLATION
AT THE TRACY WIND POWER SITE
MONTH OF APRIL 1977

DAY OF THE MONTH	TOTAL ISOLATION * (WATT-HR/M2)	TOTAL ISOLATION * (BTU/SF)
1	4135	1311
2	5928	1880
3	3503	1111
4	5049	1601
5	7347	2330
6	7407	2349
7	7525	2386
8	7495	2377
9	4285	1359
10	6983	2214
11	6329	2007
12	7826	2481
13	7216	2288
14	4826	1530
15	7675	2434
16	4701	1491
17	7318	2320
18	7416	2351
19	5287	1676
20	4654	1476
21	4933	1564
22	8271	2623
23	8207	2602
24	8309	2635
25	8386	2659
26	6690	2121
27	8455	2681
28	8383	2658
29	7005	2221
30	7162	2271
MEAN	6410	2032

* HORIZONTAL SURFACE

APPENDIX A. ENERGY DENSITY CALCULATION

On an instantaneous basis, the power in the wind is

$$P = \tfrac{1}{2} \rho A v^3$$

where P is power in kw
ρ is air density in kg/m^3
A is cross sectional area normal to the air flow in m^2
and v is the scaler air velocity in m/sec.

Power density is defined as

$$p = P/A = \tfrac{1}{2} \rho v^3$$

so energy density is the time integral of the power density as

$$E = \int^t p \, dt = \int^t \tfrac{1}{2} \rho v^3 \, dt$$

From the perfect gas law, air density can be written

$$\rho = \overline{P}/RT$$

where $\overline{P}$ is atmospheric pressure in lb_f/ft^2,
R is the gas constant for air in $ft\text{-}lb_f/lb_m\text{-}^oF$,
and T is the absolute temperature in ^oF.

The density is converted to the kg/m^3 by multiplying by 16.018.

The atmospheric pressure $\overline{P}$ varies locally within a small range due to weather conditions, but it varies significantly depending on elevation. In this analysis, atmospheric pressure is treated as a function of elevation only, as

$$\overline{P} = \overline{P}_o \exp\left((-3.744 \times 10^{-5}) z \right)$$

Where $\overline{P}_o$ is atmospheric pressure under standard conditions at sea level ($\overline{P}_o = 2116.22$ lb/ft^2), and z is elevation above sea level in ft.

With these assumptions, the energy density is

$$E = \frac{\overline{P}}{2R} \int^t \frac{v^3(t)}{T(t)} \, dt$$

where only wind speed and temperature are time dependent functions. For the numerical integration performed in hourly time steps, the energy density is

$$E = \frac{\overline{P}}{2R} \sum_{i=1}^{n} \frac{v_i^3}{T_i} \Delta t$$

where i takes on values from 1 to n hours,

and t is the one hourly time step.

The calculations of energy density were computed using the procedure outlined on the preceding page.

The frequency distribution can be used directly in the calculation of energy density, as

$$E = \tfrac{1}{2}\bar{\rho} \sum_{j=1}^{m} v_j^3 \, f_j$$

where $\bar{\rho}$ is the average density over the time period considered, j is incremental steps of wind speeds up to m, a maximum speed, and f_j is the fraction of time the wind blows at the speed j. The error introduced by this method is small since the energy density depends on the third power of the wind speed and only varies directly with the density.

APPENDIX B. WIND VELOCITY PROFILE

A wind velocity profile can be used to estimate a correction applied to wind speed data recorded at one height where power estimations are desired at another height. For an unobstructed plain, the wind velocity profile may be described as follows:

$$\frac{V}{v_o} = \left[\frac{h}{h_o}\right]^n$$

where the wind speed V at height h may be estimated from the measured speed v_o at height h_o.

The exponent n varies as follows:

$$n = 1/2 \text{ for } v_o < 5 \text{ mph}$$

$$n = 1/5 \text{ for } 5 \leqslant v_o < 35 \text{ mph}$$

$$n = 1/7 \text{ for } v_o \geqslant 35 \text{ mph}$$

Over hilly or irregular terrain, only wind speeds recorded at the site are valid for energy prediction.

APPENDIX C. ENERGY OUTPUT OF A WINDPLANT

The calculation of energy produced by a wind plant depends on two sets of information: the characteristic performance of the wind plant and frequency distribution of wind speeds. This can be written

$$E_{wp} = \sum_{v=1}^{N} P(v) \quad f(v)$$

where E_{wp} is the energy produced by the wind plant, $P(v)$ is wind plant characteristic output, ie power produced as a function of the wind speed v, and $f(v)$ is the fraction of time the wind blows at the speed v. The summation is performed from v = 1 up to a maximum speed N where the frequency of occurrence has been dropped to zero.

APPENDIX D. CHARACTERISTIC OUTPUT OF DUNLITE WIND PLANT

Wind Speed (mph)	Power Output (Watts)
1	0
2	0
3	0
4	0
5	0
6	0
7	0
8	80
9	160
10	240
11	320
12	400
13	550
14	700
15	850
16	1050
17	1163
18	1275
19	1388
20	1500
21	1600
22	1700
23	1800
24	1900
25	2000
25	2000

APPENDIX E

Frequency Distribution of Wind Speeds

at

The Tracy Wind Power Site

and

The Great Falls Airport

FREQUENCY DISTRIBUTION
FOR THE TRACY WIND POWER SITE

WIND SPEED MPH	HOURS AT SPEED	% TIME AT SPEED
1	15	2.08
2	22	3.06
3	24	3.33
4	23	3.19
5	32	4.44
6	45	6.25
7	49	6.81
8	48	6.67
9	41	5.69
10	39	5.42
11	32	4.44
12	30	4.17
13	47	6.53
14	43	5.97
15	29	4.03
16	35	4.86
17	25	3.47
18	28	3.89
19	17	2.36
20	21	2.92
21	21	2.92
22	14	1.94
23	9	1.25
24	9	1.25
25	1	.14
26	5	.69
27	3	.42
28	4	.56
29	3	.42
30	2	.28
31	1	.14
32	1	.14
33	1	.14
34	0	0.00
35	0	0.00

FREQUENCY DISTRIBUTION
FOR THE GREAT FALLS AP WEATHER STATION

WIND SPEED MPH	HOURS AT SPEED	% TIME AT SPEED
1	11	1.53
2	0	0.00
3	0	0.00
4	13	1.81
5	0	0.00
6	91	12.64
7	67	9.31
8	45	6.25
9	0	0.00
10	92	12.78
11	48	6.67
12	81	11.25
13	0	0.00
14	39	5.42
15	53	7.36
16	30	4.17
17	37	5.14
18	0	0.00
19	28	3.89
20	34	4.72
21	14	1.94
22	0	0.00
23	18	2.50
24	2	.28
25	10	1.39
26	0	0.00
27	0	0.00
28	4	.56
29	0	0.00
30	1	.14
31	0	0.00
32	1	.14
33	0	0.00
34	0	0.00
35	1	.14

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